Hanson & Wickersham

The Installation of a 45-K. W. Motor Generator

Electrical Engineering

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THE INSTALLATION OF A 45-K.W. MOTOR GENERATOR

BY

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THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

ELECTRICAL ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

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UNIVERSITY OF ILLINOIS

June 1 1908

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

FRANK LAWRENCE HANSON and CLARENCE EDMUND WICKERSHAM

ENTITLED INSTALLATION OF A 45-KILOWATT MOTOR GENERATOR

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Electrical Engineering

J M Bryant
Instructor in Charge.

APPROVED: Morgan Brooks.

HEAD OF DEPARTMENT OF Electrical Engineering

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INTRODUCTION:-

During the past two years two problems of considerable moment have presented themselves to the Electrical Engineering Department of the University. The first has resulted from the large number of students taking laboratory courses, while the second has come about from the higher standard of experimental work required. The necessarily increased size of classes has called for more current than the overloaded plant could furnish, while the higher class of experimental work has required better regulation than could be at all times obtained.

A brief description of the existing conditions may serve to illustrate the problem at hand. At the beginning of this year the rated output of the power plant was 235 K.W. of alternating current and 85 K.W. of direct current, while the connected load on the plant was three times this amount. The day load, which lasted from 8 A.M. to 5 P.M., was mostly motor with some lighting, while the night load was mostly lighting with some motors on the line. Under the most favorable circumstances the load factor was very high, and the regulation poorer than that required for some of the laboratory work. Conditions, especially on dark days, when large lighting loads were required, were often such as to heavily over-load the plant and impair the laboratory work.

In order to most satisfactorially meet these problems it was decided to move the 40 K.W. alternating current generator from the power plant into the laboratory and belt connect it to a 45 K.W. direct current generator which was in the labora-

tory, so that either machine could be run as a generator or motor. The circuits were to be so arranged that either machine could be operated in parallel with the power plant. With the motor-generator so installed it would be possible to carry either the alternating current or direct current laboratory load, and to help the power plant carry its load when necessary. Since it is the alternating current generators that are overloaded, when used to help the plant carry its load, the motor-generator set would be most often used to generate alternating current. Such a solution would aid materially in providing the necessary current and regulation for the laboratory without decreasing the output of the power plant.

DESCRIPTION OF APPARATUS

Both generators were made by the Westinghouse Electric and Manufacturing Company. The A.C. generator is designed for 900 R.P.M., two phase, 440 volts and is rated at 40 K.W. It has eight poles and a commutating device which is used to rectify the current sent through the compounding coils on the fields. The D.C. generator is designed for 850 R.P.M., is three wire, 125-250 volts, 180 amperes, which gives it an output of 45 K.W.

The D.C. neutral is obtained by Dobrowolskie's method, four slip rings being included on the shaft, connected to the armature in quarter phase relation, and the neutral obtained from connection through two transformers. The starting switch has five points and is connected with a rheostat in the basement. The field switches are of the quick break, discharge resistance type with carbon break. All of the No. 12 and No. 14 wire connections are made with white underwriters' wire. The rest of the connections are made with black rubber covered wire. The resistances for the meters are held by an iron-bracket fastened to the iron frame supporting the panels. The current transformers on the back of the A.C. generator panel are supported in a similar manner. A fuse panel, thirty-two inches long and eight inches wide, carrying eight fuses, is supported back of the A.C. feeder panel by iron brackets fastened to the frame of the panel. The generators rest on their iron foundations and ways, which are bolted directly to the floor. The building is of mill construction, the heavy floor

making a sufficiently solid foundation for the machines. The wiring from the machines to the boards runs on cleats under the floor. The description of the remainder of the apparatus is found in the List of Apparatus and may be seen in the cuts

POSITION IN LABORATORY

The D.C. feeder and generator panels and the A.C. generator panel are placed four feet from the east wall of the main laboratory, just north of the main entrance. The two machines are immediately in front of these three panels with belt running north and south parallel with the switchboard. The machines are fourteen feet apart with the A.C. generator to the south. The A.C. feeder panel is the north panel of the south switchboard in the laboratory, and was placed there for convenience to the A.C. side of the room.

DIRECT CURRENT CIRCUITS

In the direct current circuits the three wire system is used throughout so that either 110 or 220 volts may be obtained. (see diagrams, Plate G). Two sets of bus-bars are provided, both of which are connected to each of the eight laboratory plug panels. The circuits are so arranged that either or both of these buses may be connected to either the power plant, or the direct current machine, or to both. Two triple-pole, double-throw switches are provided for this purpose and are located near the bottom of the feeder panel. By closing the switches downward the bus-bars are connected to the power plant, while

by closing them upwards the buses are connected to the direct current machine. The machine may be connected directly to the power plant by closing the three pole, single throw switch near the bottom of the generator panel.

Between each set of busbars and the double-throw switches are two single-pole over-load circuit breakers. Each of these is provided with a trip coil so connected that when one of the breakers is opened by an excess of current the coil trips the breaker on the other side of the line.

The direct current generator field switch is connected in with a resistance as shown, and is located to the right and near the middle of the generator panel. The field resistance is in the middle of the panel. A starting resistance switch, located to the left and near the middle of the board, is provided, whereby resistance may be gradually cut out as the machine is brought up to full speed. When full speed is reached the outside circuit switch may be closed and the resistance switch opened.

The armature of the D.C. machine is protected by means of a double pole circuit breaker, which is set to open at 200 amperes. This breaker is located at the top of the generator panel.

An ammeter is provided for each outside wire of the generator circuit, and by means of double-pole, double-throw switches, it is possible to read the current when the D.C. machine is running either as a motor or a generator.

Near the middle of the feeder panel is a voltmeter so

connected to a six point receptacle that, when the plug is inserted in the left side of the receptacle, the power plant voltage is indicated, and, when inserted in the right side, the generator voltage is indicated.

ALTERNATING CURRENT CIRCUITS

The alternating current circuits are supplied with two phase current at 440 volts. This voltage is stepped down to 110 and 220 volts by means of ~~a~~ transformers, the three wire system being used in the transformer secondaries.

Two sets of busbars are provided, on set for 440 volts, and the other set for 110 and 220 volts. The system is so designed that either or both sets of buses may be connected to the power plant, the alternating current generator, or to both. Two four-pole double-throw switches, located near the middle of the feeder panel, are provided for making these connections. As in the direct current circuits, the busbars are connected to the A. C. machine by closing the switches upward, and to the power plant by closing them downward. The circuit of the A.C. machine may be connected directly to the power plant by means of the double-pole, single-throw switches, one for each phase, located on the feeder panel.

A synchroscope is so connected as to indicate when the A.C. generator and power plant circuits may be thrown in parallel. Two receptacles, one "running" for the power plant, and the other "starting" for the A.C. generator, are provided so that the relative speed and electromotive force vector positions

are indicated by the synchroscope by inserting the plugs in their proper positions.

The A.C. machine is separately excited from the direct current busses, the rheostat for regulating this current being placed on the A.C. generator panel. The field switch is double-pole, single-throw, and is provided with a discharge resistance of two 32 candle power lamps in series.

In snychronizing with the plant, the field switch is closed and the A.C. machine run as a generator, the driving power being supplied by the direct current machine. The synchronizing plugs are then inserted in their respective receptacles and the relative speed and voltage of the two currents so adjusted as to bring the machines into synchronism. When synchronism is reached the machines are thrown in parallel by closing the A.C. generator switches. These switches are located near the middle of the A.C. generator panel and consist of one double-pole and two single-pole, single-throw switches. The A.C. generator armature is protected from excessive currents by means of 65 ampere fuses.

An ammeter is provided for each phase, connections being made to the 440 volt circuit through current transformers. A field ammeter is also provided for measuring the field current. An indicating wattmeter is provided with two double-pole double-throw switches, for indicating the watts, both when the A.C. machine is running as a motor, and as a generator. A voltmeter is connected to a six point receptacal that indicated the power plant voltage when the plug is in the left openings and the generator voltage when in the right openings. A frequency meter

is included, having one of its terminals connected to one side of the 440 volt dircuit and the other two terminals, which are in parallel, on the other side of the line. An inductive synchronizing coil, openings for the connections of which are near the bottom of the feeder panel, is so connected that by inserting the plug in these openings, the motor-generator and the power plant may be thrown in parallel as soon as the voltage of the two machines is the same, the coil bringing them into synchronism after they are thrown in parallel.

SPECIAL FEATURES

The A.C. machine may be synchronized with the power plant in two ways, by use of the synchrosdope with starting and running plugs, or by use of the synchronizing coil. The tie switches and the double-throw switches, connecting the set with the power plant or the laboratory, are special features. A mercury-vapor rectifier is installed directly south of the three panels so that the A.C. generator field may be excited by its own rectified current. A heavy brass railing surrounds three sides of the motor-generator set, the switchboard forming the fourth side, and gives it the appearance of a distinct unit in the laboratory.

SUGGESTIONS FOR IMPROVEMENT

Two improvements might be made over the present installation. The divisions of the rheostat on the D.C. generator panel are found to be too large, each notch giving too much

change of torque to the D.C. machine. This makes it difficult to regulate the load on the A.C. machine, when the set is run in parallel with the power plant. The ammeters, which are designed to be used with the D.C. machine, have a range of from 0 to 200 amperes. With the commercial rating of the machine these meters would read only ten per cent overload and with the rating as found by the heat run, the range of the meters should be from 0 to 300 amperes.

OPERATION

HEAT RUN AND RATING

The generator set was run for seven hours with the D.C. machine as motor. The A.C. machine was synchronized with the University power plant and carried an average load of 33.7 K.W. From calculations of the data the rating of the A.C. **generator** is found to be 46 K.W. This is six K.W. more than the commercial rating, which means that the machine may carry 15 % overload continually without overheating. By the use of the thermometer method of obtaining the rise in temperature, the rating of the direct current generator is found to be about 58 K.W. This method of rating was used instead of the resistance method, because of an error due to the instruments in obtaining the hot resistance of the armature. As seen from above, the machine is considerably under-rated, this being due to the fact that since the machine was made, the standard of rating has been materially changed, a higher rating now being permitted than was formerly allowed.

EFFICIENCY OF MOTOR-GENERATOR SET

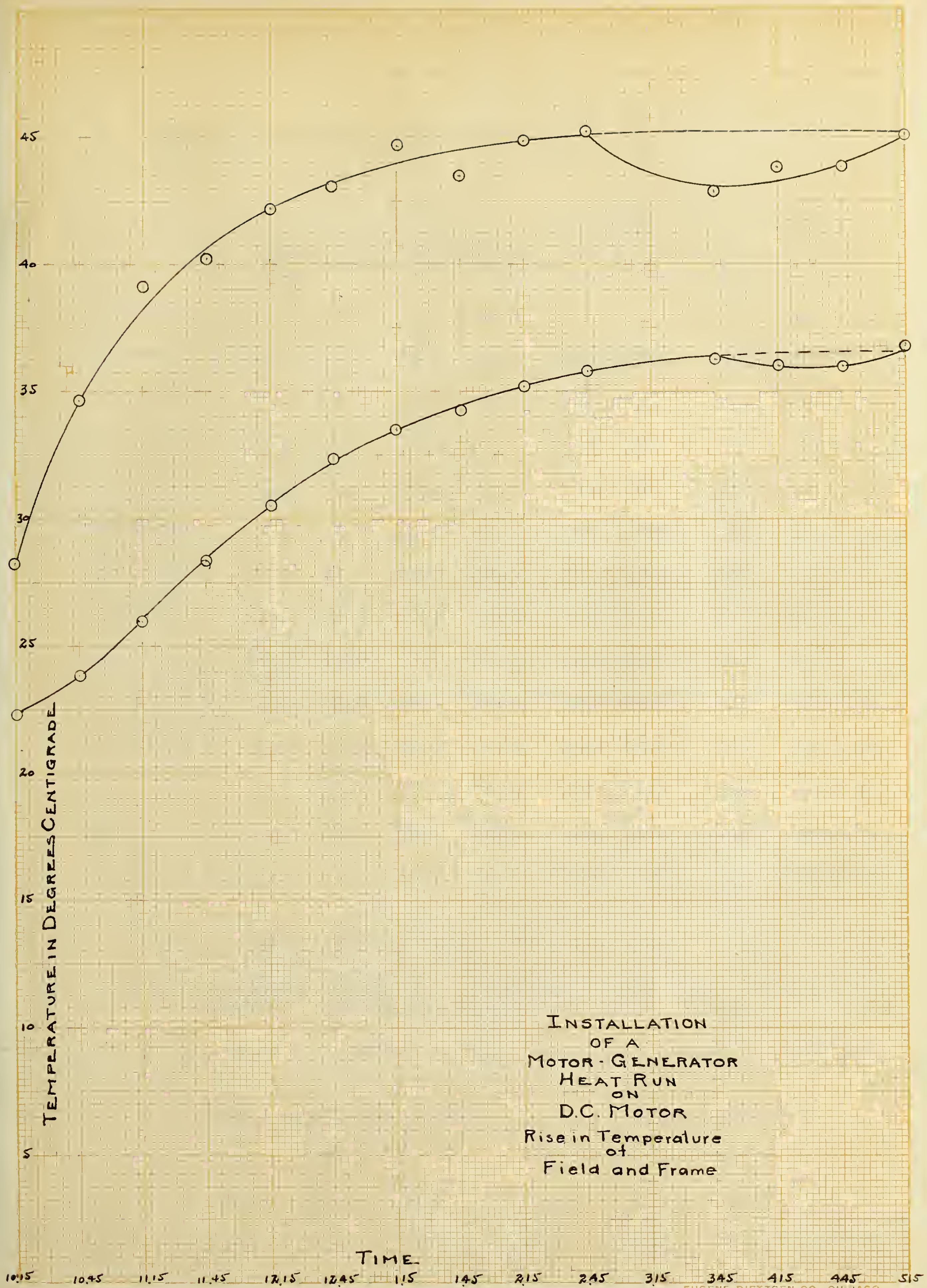
The efficiency of the motor-generator set, running the D.C. machine as a motor and the A.C. machine as a generator, is 98.8%; and running the reverse way, is 76.2%. This latter efficiency was not taken under very favorable conditions, so the correct efficiency is close to 80%.

OPEN CIRCUIT VOLTAGE

The range of voltage given by the operation of the rheostats when the generators are on open circuit are as follows: When the D.C. machine is run as a motor with the highest field excitation, the rheostat of the A.C. machine permits a range of voltage from 275 to 440, and with lowest excitation from 370 to 590 volts. When the A.C. machine is run as a synchronous motor the rheostat of the D.C. machine allows a range of from 98 to 282 volts.

TWENTY FIVE CYCLE CURRENT

It is found that the A.C. machine when run as a synchronous motor from the power plant, will give practically twenty-five cycles from the slip rings on the D.C. machine, used to obtain the neutral.



INSTALLATION
OF A
MOTOR-GENERATOR
HEAT RUN
ON
D.C. MOTOR
Rise in Temperature
of
Field and Frame

HEAT RUN ON MOTOR GENERATOR SET

D.C. MOTOR

Time	Field Temperature			Frame Temp.		Armature Current			Room Temp.	
	F_1	F_2	Correct	F	Correct	A_1	A_2	E.M.F.	T_1	T_2
10:15	28.1	27.0	28.3	22.0	22.2				23.0	23.0
10:45	34.5	33.0	34.7	23.8	23.9	150	154	250	24.0	23.9
11:15	38.0	37.0	38.1	26.0	26.0	164	166	250	24.8	24.6
11:45	40.2	39.8	40.2	28.4	28.4	158	160	248	25.0	24.9
12:15	42.2	41.8	42.2	30.5	30.5	159	161	248	25.7	25.0
12:45	43.3	43.0	43.2	32.4	32.4	166	165	246	25.3	25.0
1:15	44.8	43.5	44.6	33.5	33.5	161	162	247	25.1	25.3
1:45	44.0	43.8	43.5	34.4	34.2	150	148	243	26.2	26.1
2:15	45.2	45.0	44.9	35.5	35.1	152	154	240	26.6	26.4
2:45	45.8	45.0	45.3	36.1	35.8	159	160	244	26.9	26.3
3:45	42.8	42.2	42.8	36.2	36.2	158	160	245	26.7	25.0
4:15	44.0	43.5	44.0	36.0	36.0	156	158	242	25.0	24.8
4:45	44.0	43.2	43.9	36.0	36.0	158	158	244	24.6	24.4
5:15	45.0	45.0	45.1	37.0	36.9	158	158		25.6	25.2

Temperatures taken after the run

Armature Reading	Reading Corrected	Bearings		Pole Tips		Field	Commutator
		Right	Left	Lead.	Trail.		
58.0	58.0	50	49.2	51.7	49.7	50.6	57.

Field Resistance hot			Field Resistance cold		
E	I	R	E	I	R
224	2.1	106.6	242	3.45	70.2
232	2.2	105.5	226	3.25	69.5

Temperatures taken after the run, continued:-

Field resistance hot			Field resistance cold		
E	I	R	E	I	R
240	2.3	104.2	210	3.05	69.0
250	2.4	104.1	196	2.87	68.5
			168	2.70	62.2

Average resistance hot = 105.1

Average resistance cold = 69.3

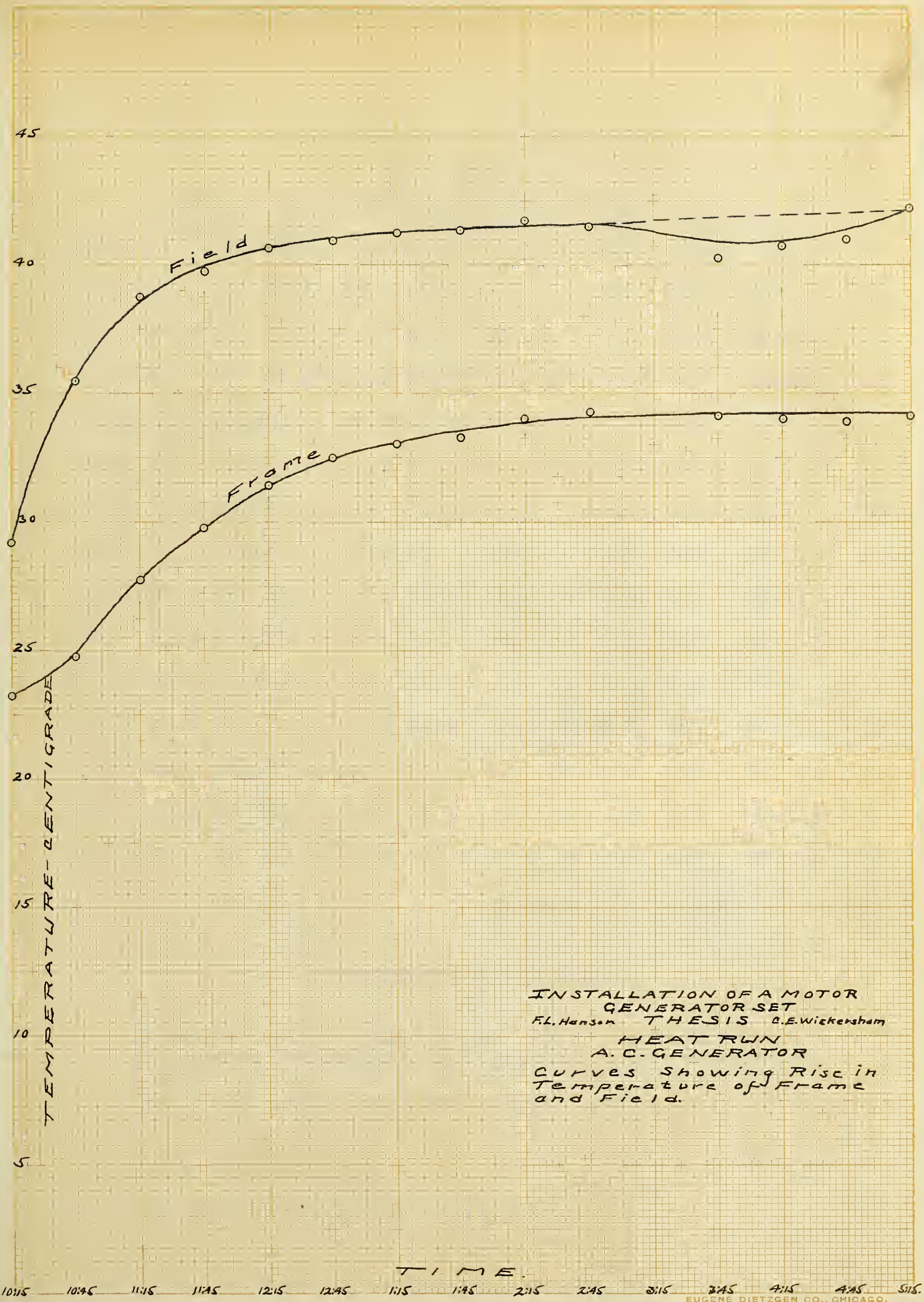
HEAT RUN ON MOTOR GENERATOR SET

Part of Motor	Actual rise of Temp above Room temp.	Permiss-able Rise	Differ-ence
Field	25.4	50°	24.6
Armature	32.8	50°	17.2
Commutator	31.8	55°	23.2
Pole Tips			
Leading	26.5	50°	23.5
Trailing	24.5	50°	24.5
Bearings	25.8	40°	14.2
Frame	24.5	40°	15.5

Rating of machine from heat run = 58.5 K.W.

Commercial rating of machine = 45 K.W.

Percent overload that can be carried continually = 30



INSTALLATION OF A MOTOR GENERATOR SET
F.L. Hanson THESIS C.E. Wickersham
HEAT RUN
A.C. GENERATOR
Curves Showing Rise in Temperature of Frame and Field.

HEAT RUN ON MOTOR GENERATOR SET

A.C. GENERATOR

	Field temper.		Cor. Field	Frame	Temp	Armature current		Field cur-	Gen.	Room temp.		
Time	F_1	F_2	Temp	T_F	Corrected	I_1	I_2	rent	E.M.F.	T_1	T_2	Av.
10:15	30	28	29.3	23	23.2			6.2	450	23	23.	23.
10:45	36.6	34	35.5	24.7	24.8	35	37	6.2	450	24	23.9	24.
11:15	40	37	38.6	27.8	27.8	40	40	6.3	455	24.8	24.6	24.7
11:45	41.2	38.2	39.7	29.9	29.9	39	37	6.1	452	25	24.9	25.
12:15	42	40.1	40.6	31.4	31.4	40	38	6.1	460	25.1	25.	25.1
12:45	42.5	39.1	40.9	32.5	32.5	39	40	6.1	454	25.3	25.	25.2
1:15	42.7	39.7	41.3	33	33	38	40	6.1	448	25.1	25.3	25.2
1:45	43	40	41.3	33.5	33.3	38.5	36.5	6.0	452	26.2	26.1	26.2
2:15	43.8	40.2	41.7	34.2	34	38	38	5.8	455	26.6	26.4	26.5
2:45	43.8	39.8	41.5	34.6	34.4	41	41	6.0	455	26.9	26.3	26.6
3:45	42.2	39	40.4	34.2	34.1	38	39	6.1	450	26.7	25.	25.9
4:15	43	38.5	40.8	34	34	38	38	6.1	450	25.	24.8	24.9
4:45	42.8	39.2	41.0	33.8	33.9	38	38	6.2	450	24.6	24.4	24.5
5:15	44	41	42.4	34.2	34.1	37	36	6.4	450	25.6	25.2	25.4

Av.38.4 Av452 Av =25.1

Temperatures after run

Armature		Slip	Bearings		Av. Temp	Pole Tips		
A_T	Correct.	Rings	Right	Left	Bearings	Lead.	Trail.	Field
48	47.9	34.5	38.5	37.1	37.8	53.3	48.0	50.3

Power factor = .97

Average load carried = 33.7 K.W.

Field resistance hot

E	I	R
65	4	16.2
76	4.5	16.9
84.5	5	16.9
102	6	17

Field resistance cold

E	I	R
72.5	5	14.5
89	6	14.8
104	7.1	14.7
111	7.5	14.8

Average resistance hot = 16.75

Average resistance cold = 14.7

Room temperature = 23.2° C

HEAD RUN ON MOTOR GENERATOR SET

A.C. GENERATOR

Part	Actual Rise in Temp Above Room	Permissable rise Above room	Difference
Fields	By res. 36.6	50	13.4
Armature	By ther 22.5	50	27.5
Fields	24.9	50	25.1
Rings	9.1	55	45.9
Bearings	12.4	40	27.6
Pole Tips			
Leading	27.9	40	12.1
Trailing	22.6	40	17.4
Frame	8.7	40	31.3

Rating of machine from Heat run = 46 K.W.

Commercial rating of machine = 40 K.W.

Per cent overload that can be carried continually = 15

EFFICIENCY OF MOTOR GENERATOR SET

D.C. MOTOR				A.C. GENERATOR				% EFFICIENCY OF SET	
A_1	A_2	V	W	A_1	A_2	V	W		
152	154	250	38.25	37.5	40	410	31.5	82.3	Av.
163	165	250	41	39.5	41.5	408	32	78.5	79.8
180	180	250	45	44	46.5	400	35	77.7	
D.C. GENERATOR				A.C. MOTOR				% EFF. OF SET	
A_1	A_2	V	W	A_1	A_2	V	W		
23	24	235	5.25	20	12.5	462	10	55.2	Av.
45	46	232	10.55	25	18	462	15	70.4	76.2
44	46	237	10.66	25	19	450	13	82.0	

OPEN CIRCUIT VOLTAGES

D.C. as motor D.C. Field Zero A.C. Rheostat gives 275 - 440

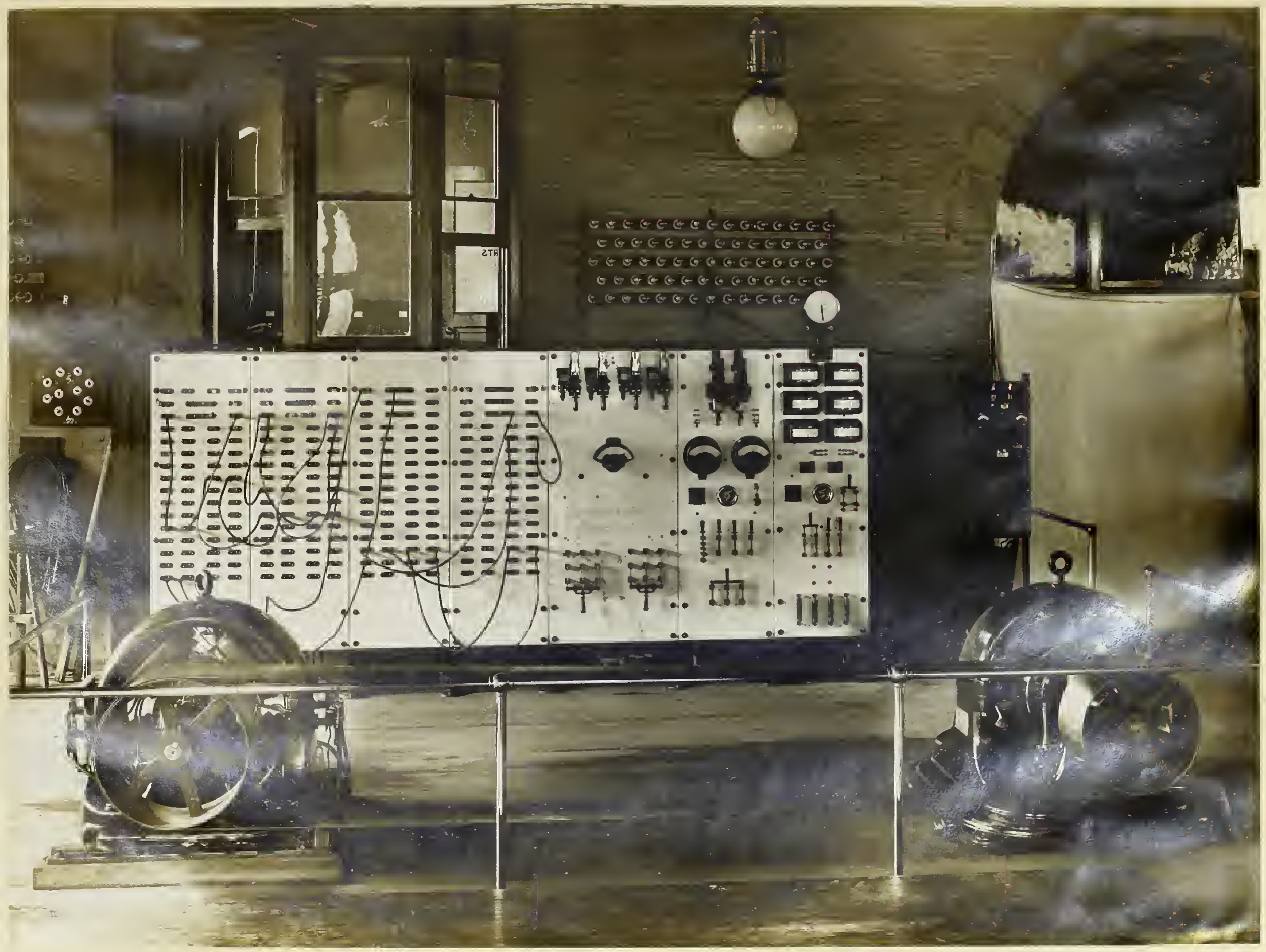
" " " D.C. Field Full " " " 370 - 590

A.C. as Syn Motor D.C. Rheostat gives 98 - 280

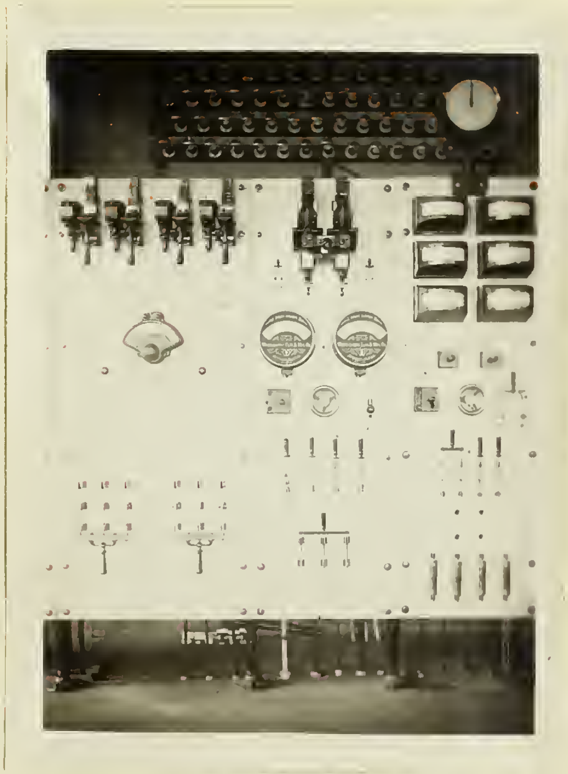
LIST OF APPARATUS

		COST
1	Starting Rheostat Type IG G.E.Co. 250 volts	14.00
4	Single pole circuit breakers 300 Amps. 250 volts	156.00
3	Voltmeter receptacles and Plugs, six point G.E. Co. and,	20.00
2	Synchronizing receptacles and plugs four point G.E.Co.	
1	Synchronoscope and Bracket G.E.Co.	50.00
1	Starting switch 4 T.S.P. 200 amperes	15.00
1	Field switch, single pole G.E.Co. 100 Amp. 250 volts	7.00
1	Field switch double pole G.E.Co. 100 Amp. 250 volts	12.00
2	Switches single pole, Quick Break G.E.Co. 100 Amp.	8.00
1	Switch double pole Quick Break G.E.Co. 100 Amp. 600 volts	7.00
3	Switches S.P.S.T. G.E.Co. 200 Amp. 250 volts D.C. 500 V.A.C.	7.50
1	Switch S.P.S.T. G.E.Co. 200 Amp. 250 volts D.C. 500 volts A.C.	5.75
2	A.C. Ammeters Thompson G.E.Co. Range 0-80 Style N.P.4777 H	60.00
1	A.C. Ammeter Thompson G.E.Co. Range 0-20 Style N.P. 4777 H	30.00
1	A.C. Voltmeter Thompson G.E.Co. Range 0-750 Style NP4777H	40.00
2	Current transformers 25-125 cycles, 40 watts, 80 Amp. Ratio 16 - 1	30.00
1	Wattmeter, Thompsonnindicating polyphase, Range 0-80 K.W.	62.50
1	Frequency meter G.E.Co. Range 40-100	50.00
1	D.C. Voltmeter #17440 G.E.Co. Range 0-350	20.00
1	Circuit Breaker, double pole I.T.E. Cutler Co. 200 Amp. 250 volts	108.00
2	D.C. Ammeters, Westinghouse, Range 0-200	40.00
2	Switches 3 P.D.T. Westinghouse 200 Amp. 250 volts	19.00
4	Switches D.P.D.T. Small, 2 for ammeters, 2 for wattmeter	4.00

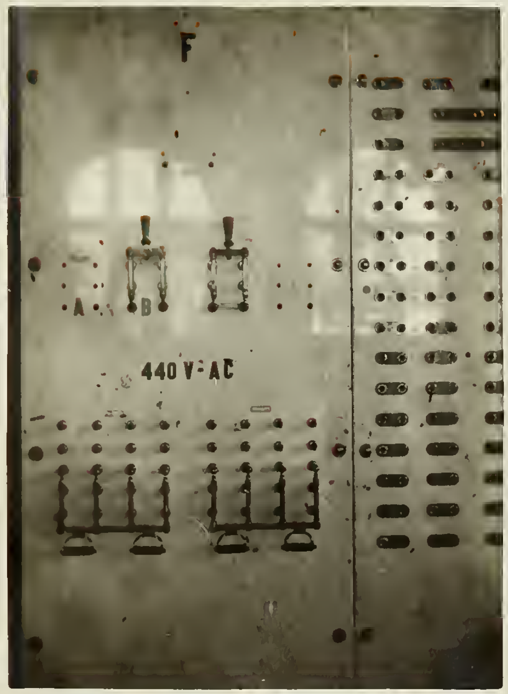
2	Rheostats, Cutler Hammer:250 volts. Max. Amp. 5-2.5 Min field ohms 60;125 volts,Max. Amp. 10-5 Min field 15	22.00
8	Fuses and Terminals D and W, Non Arcing 65 Amp 600 volts	6.32
4	Fuses and Terminals D and W, Non Arcing 20 Amp. 600 volts	2.00
2	Marble Panels and Supports 24" wide 6' high	40.00
2	Marble Panels and Supports 32" wide 6' high	53.00
1	Marble Panel and Supports, for fuses 32" long 8" wide	3.00
2	Crouse-Hinds D.P.S.T. Switches 75 Amp. 300 volts	12.00
2	Crouse-Hinds 4.P.D.T. Switches 75 Amp. 300 volts	20.00
	Cleat, wire and Sundries	20.00
1	Westinghouse 45 K.W. Generator #53128, 900 Rev. 2 Phase, 440 Volts.	900.00
1	Westinghouse 45 K.W. D.C. Generator 125-250 Volts, 180 Amps. Speed 850. and transformers for neutral	1200.00
	Coil for synchronizing	10.00
	Labor Estimated at	275.00
	Total =	$ 3329.07



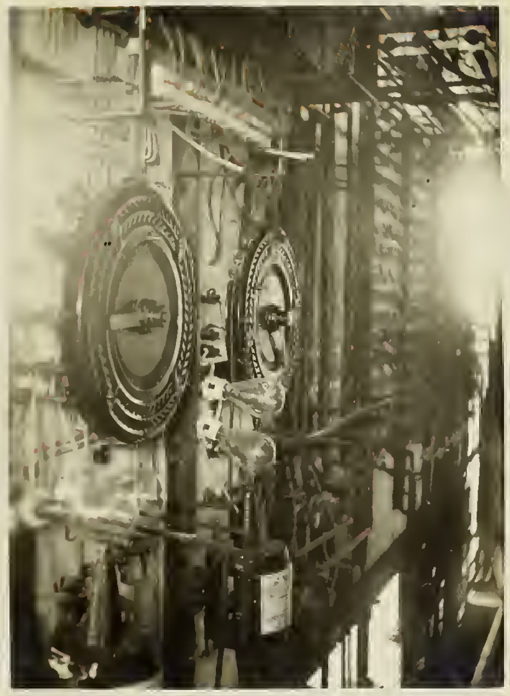
MOTOR-GENERATOR AND NORTH SWITCHBOARD



D.C. FEEDER AND D.C. AND A.C. GENERATOR PANELS

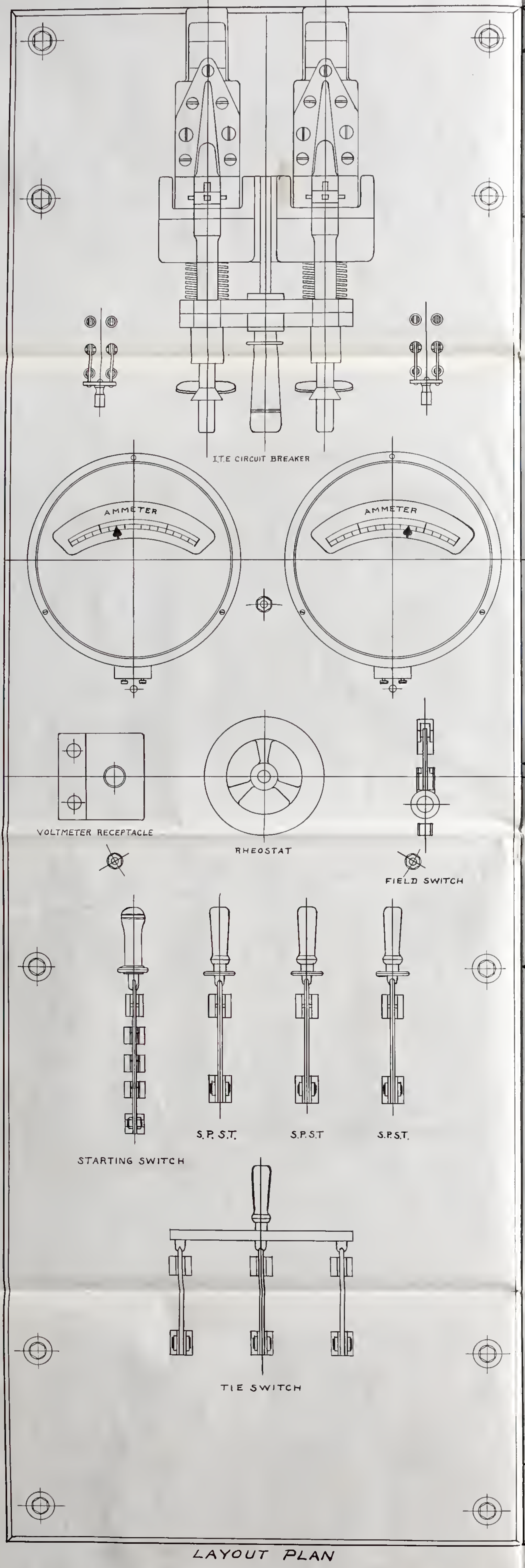


ALTERNATING CURRENT FEEDER PANEL

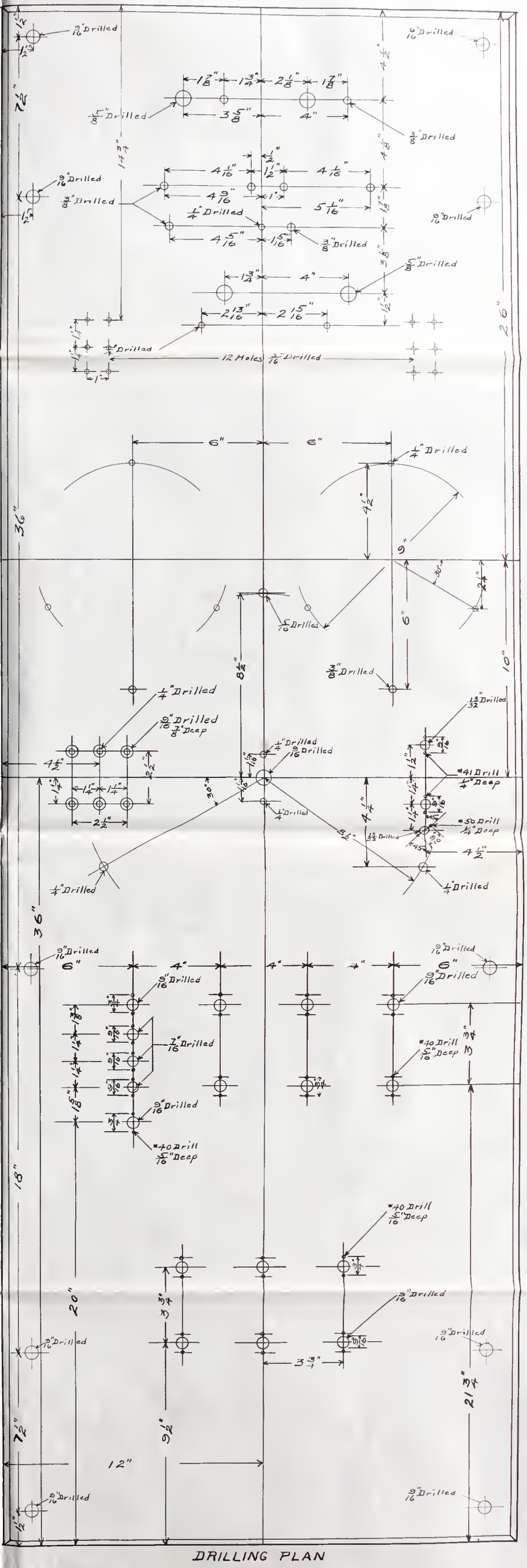


REARVIEW OF PANELS

A.



LAYOUT PLAN



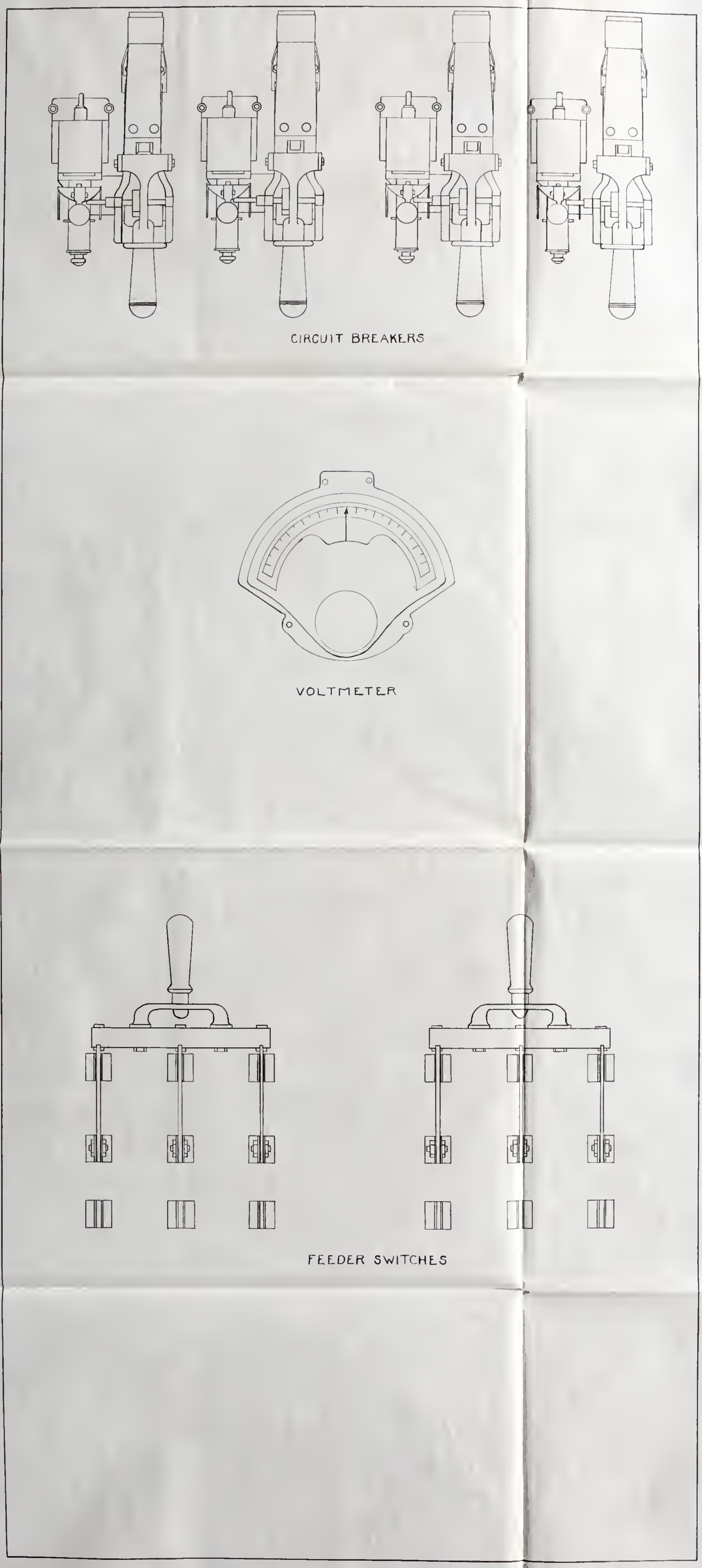
DRILLING PLAN

D. C. GENERATOR PANEL

HANSON THESIS WICKERSHAM

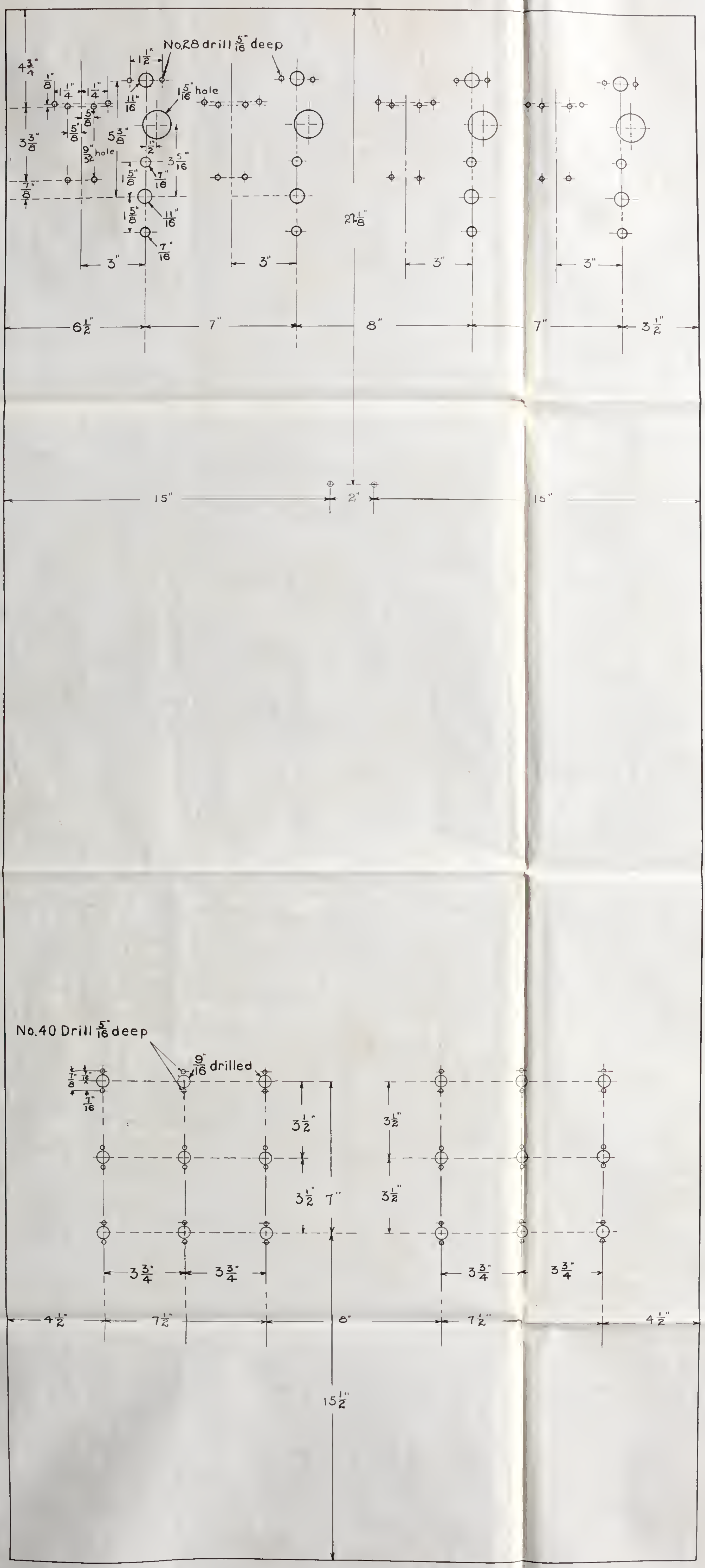
INSTALLATION OF A MOTOR GENERATOR

B



D.C FEEEDER PANEL
Hanson THESIS Wickersham
INSTALLATION OF A MOTOR GENERATOR

C

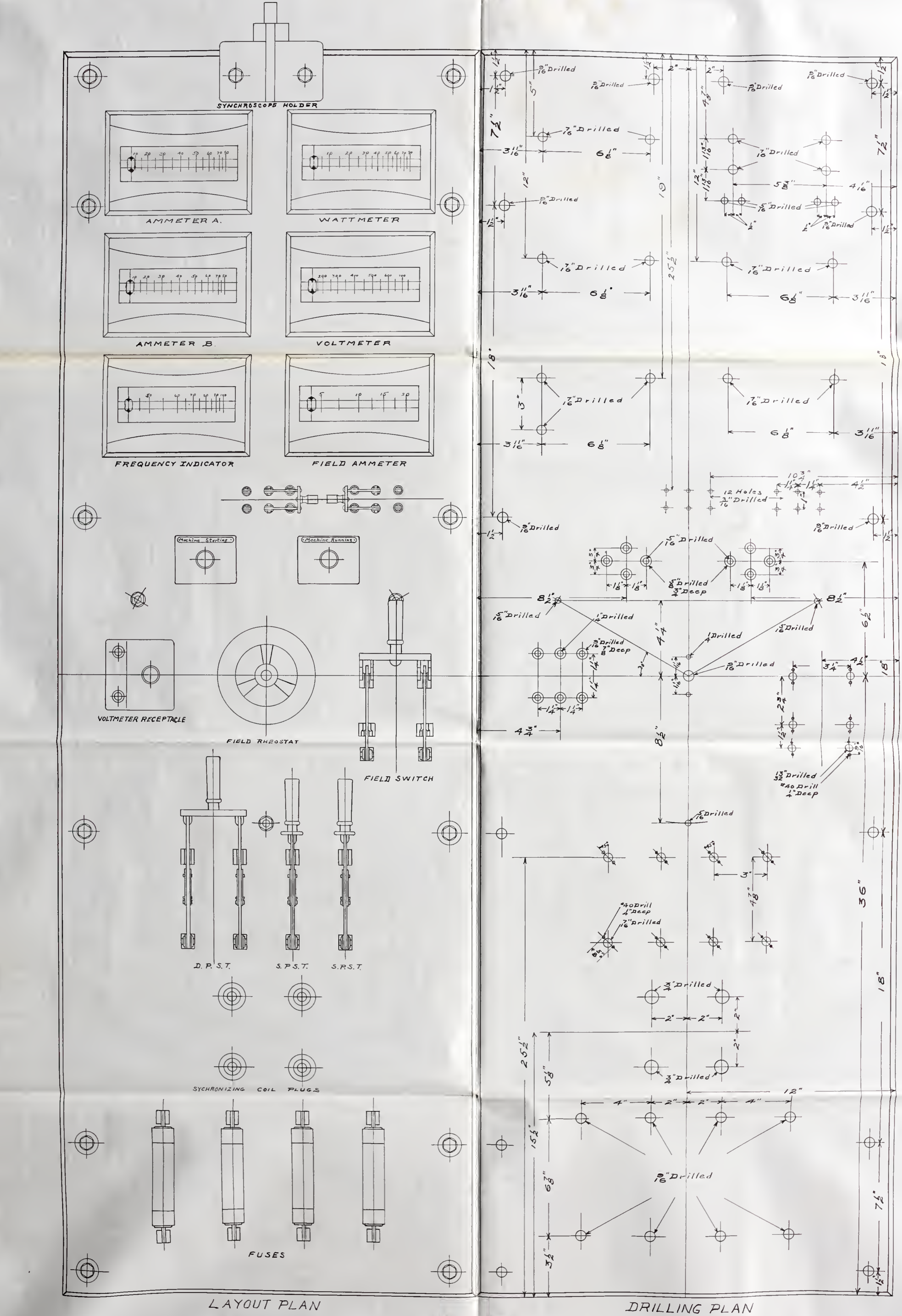


DRILLING PLAN FOR FEEDER PANEL

Hanson THESIS Wickersham

INSTALLATION OF A MOTOR GENERATOR

D.



LAYOUT PLAN

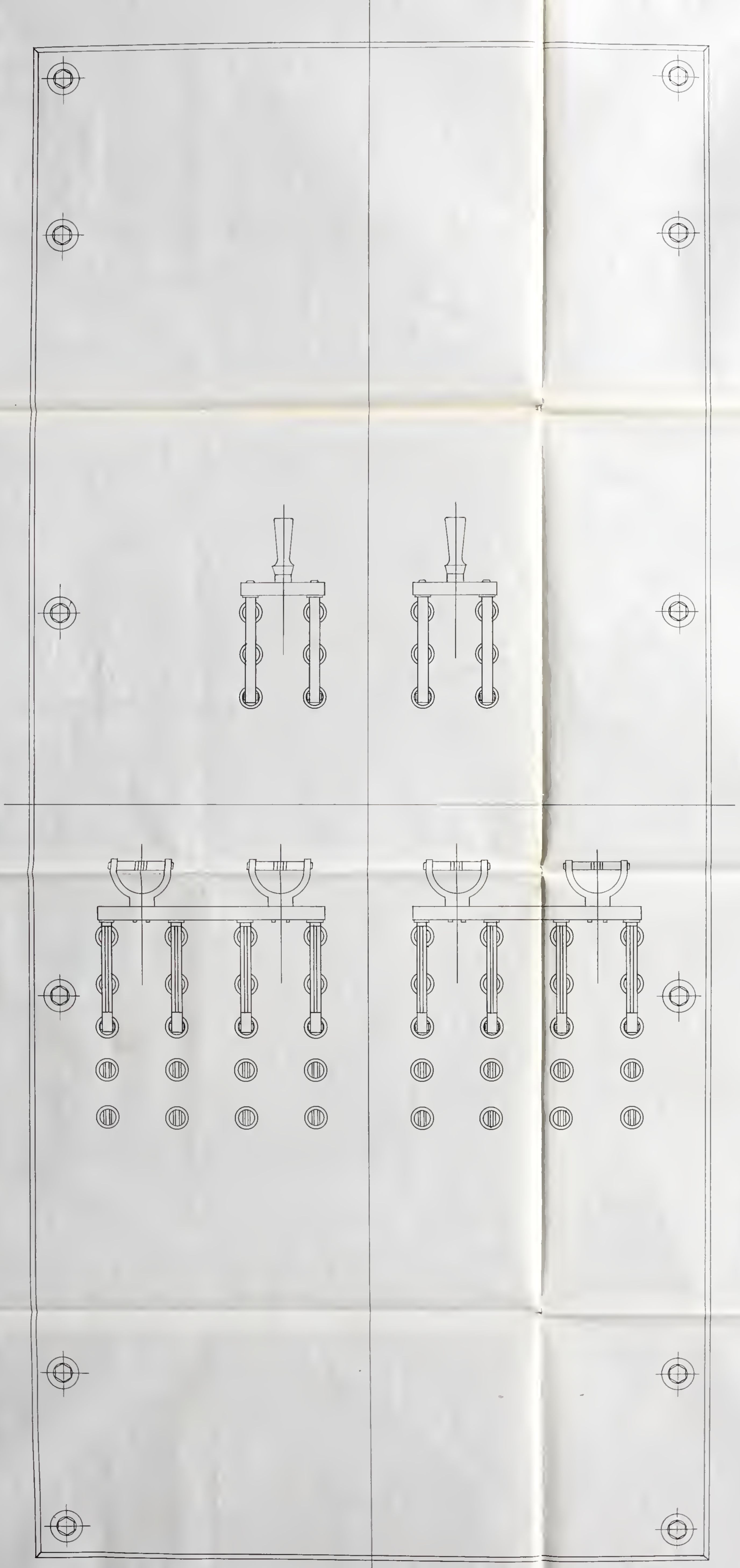
DRILLING PLAN

A.C. GENERATOR PANEL

HANSON THESIS WICKERSHAM

INSTALLATION OF A MOTOR GENERATOR

E

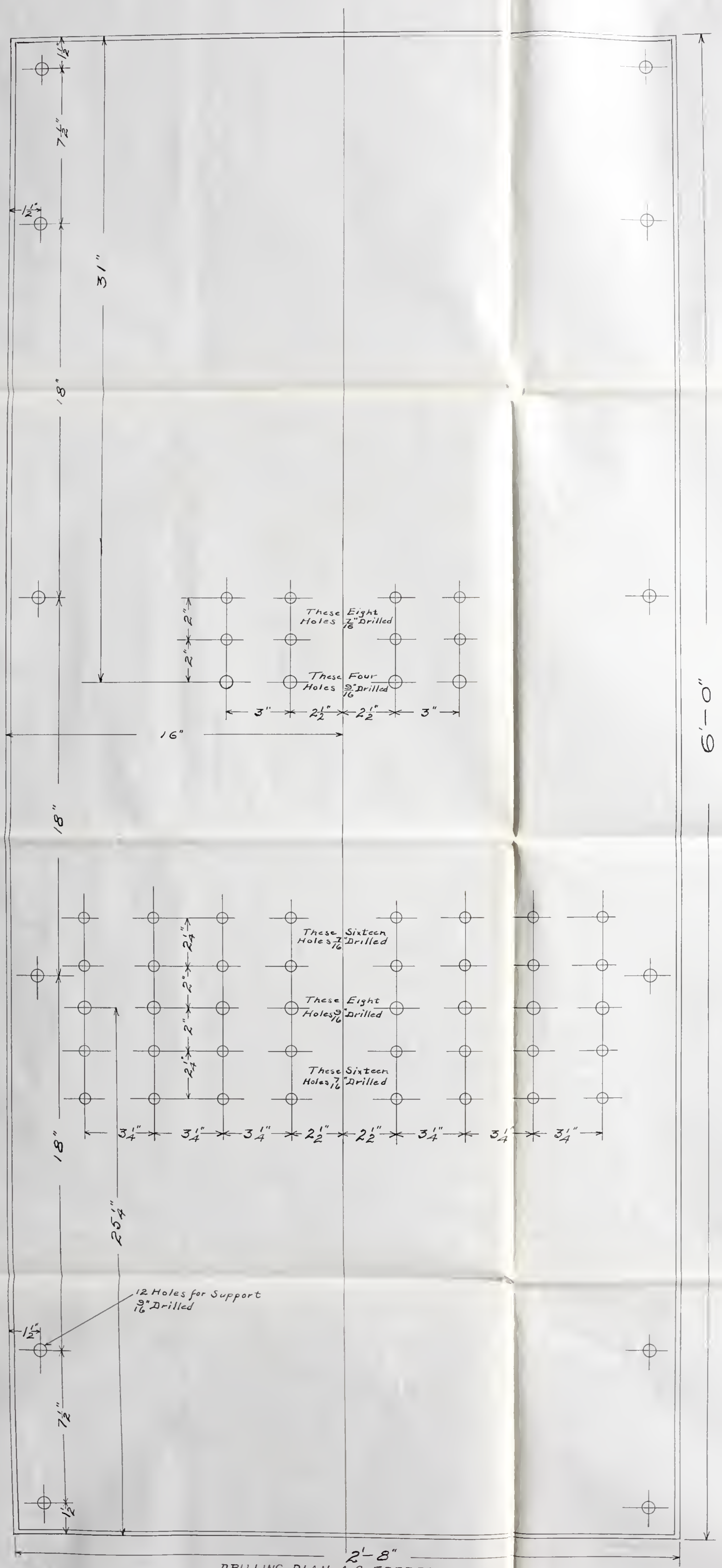


LAYOUT PLAN, A. C. FEEDER PANEL

HANSON THESIS WICKERSHAM

INSTALLATION OF A MOTOR GENERATOR

F

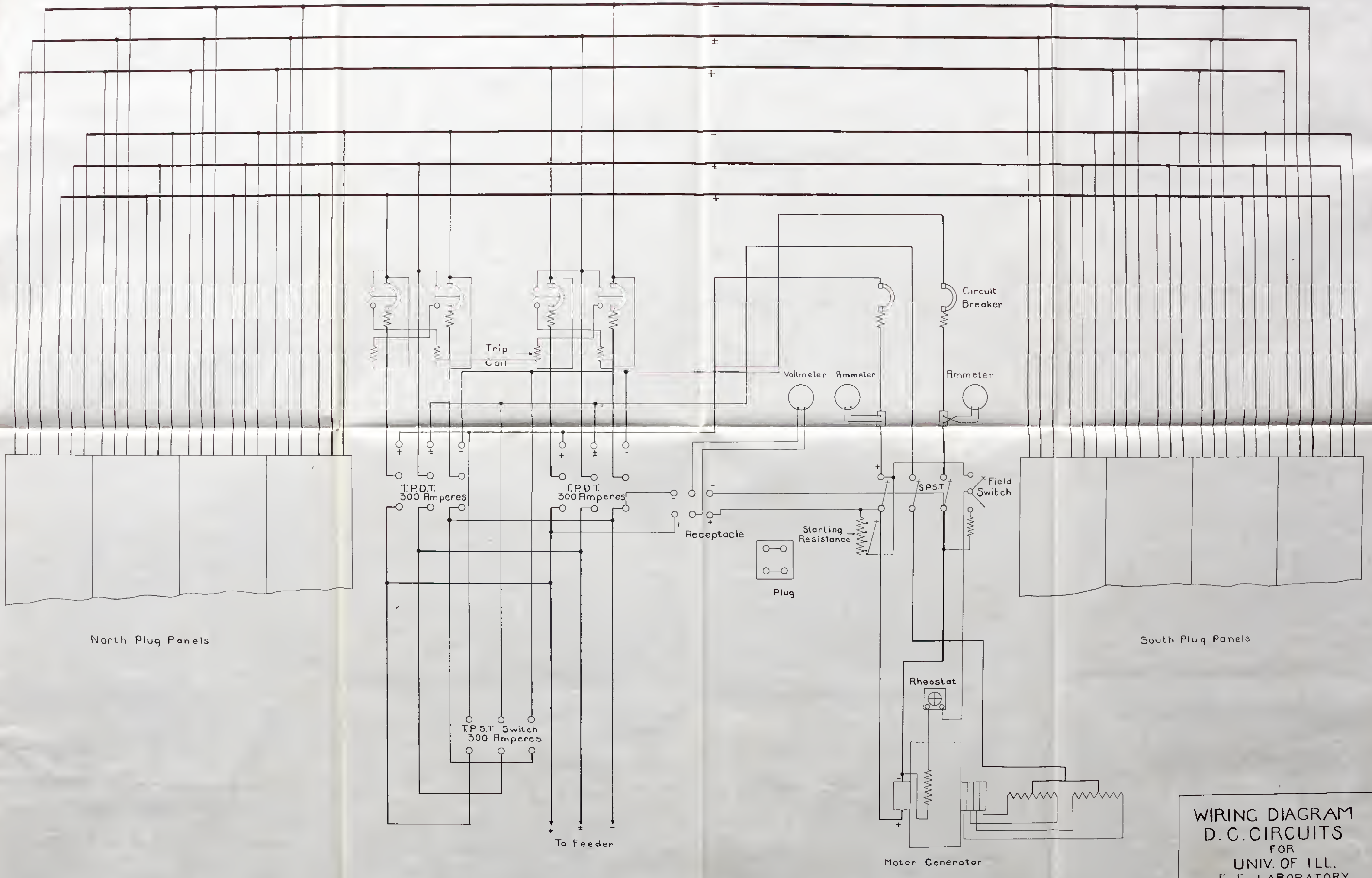


DRILLING PLAN, A.C. FEEDER PANEL

HANSON THESIS WICKERSHAM

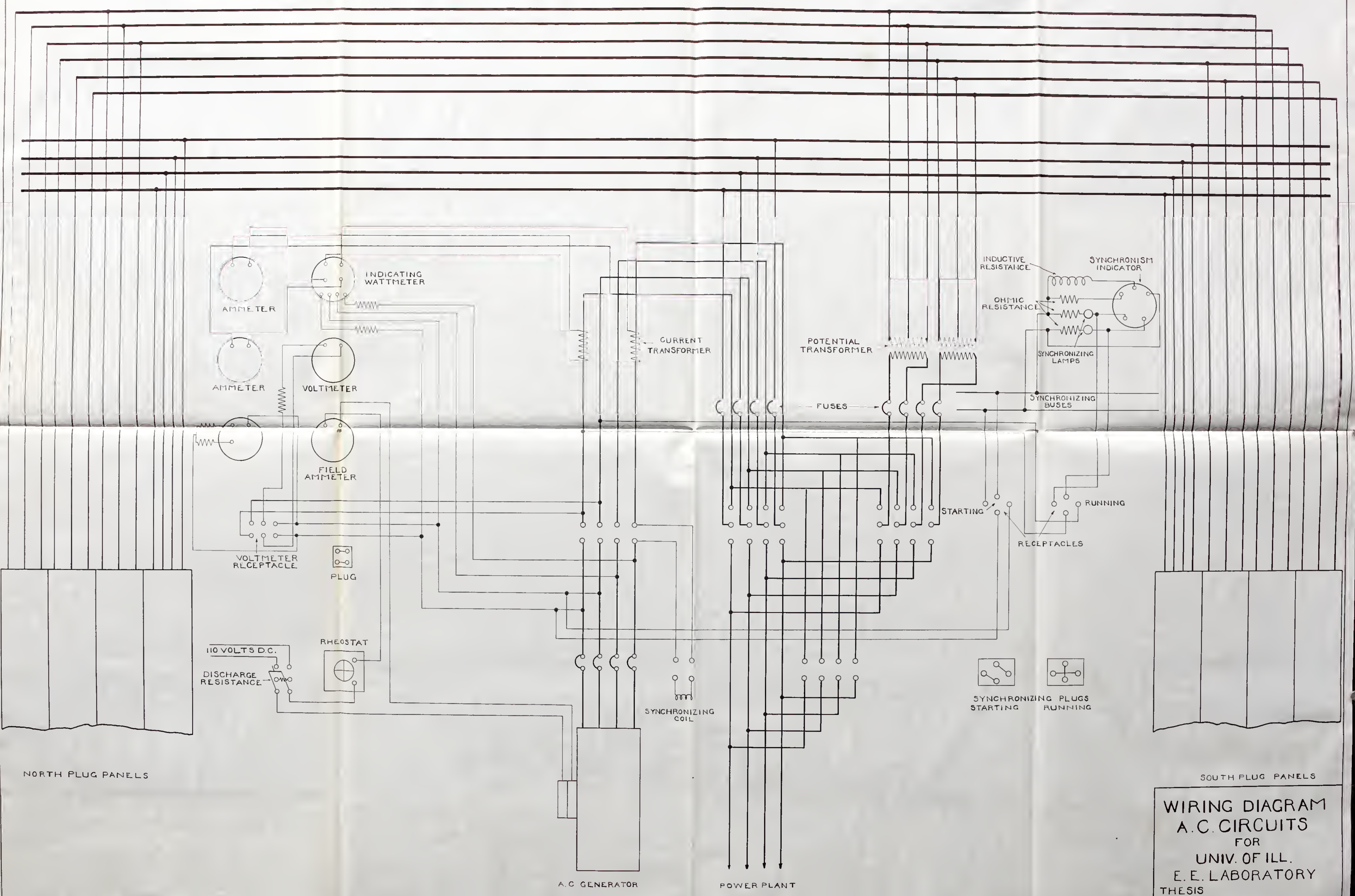
INSTALLATION OF A MOTOR GENERATOR '08

G

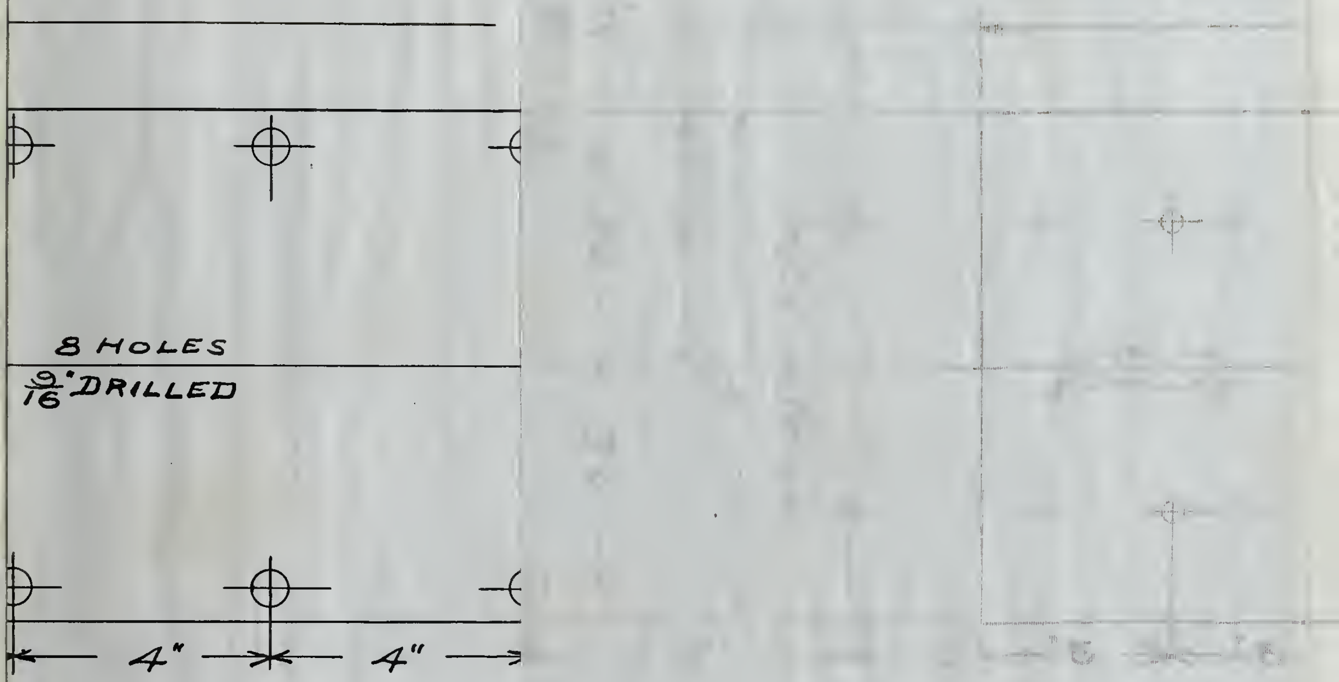


WIRING DIAGRAM
D.C. CIRCUITS
FOR
UNIV. OF ILL.
E.E. LABORATORY
THESIS
WICKERSHAM AND HANSON
Feb 1908

H



WIRING DIAGRAM
A.C. CIRCUITS
FOR
UNIV. OF ILL.
E. E. LABORATORY
THESIS
WICKERSHAM & HANSON



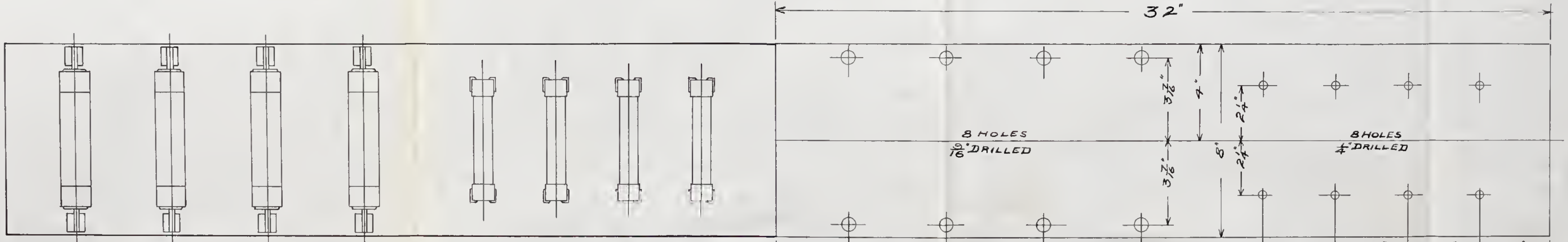
DRILL

PANEL

ERSHAM

TOR

I.



LAYOUT PLAN

DRILLING PLAN

FUSE PANEL TO GO IN BACK OF A.C. FEEDER PANEL

HANSON THESIS WICKERSHAM

INSTALLATION OF A MOTOR GENERATOR